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Observation of Solar Cosmic Rays

The following material was prepared by P. S. Freier, E. P. Ney, and J. R. Winckler, of the School of Physics, University of Minnesota. A more detailed report was published in the Journal of Geophysical Research, *June 1959.*

A very unusual series of solar and terrestrial phenomena occurred in late March 1958, culminating in the arrival at the earth of low-energy cosmic rays. These events probably resulted from a solar flare of importance 3+ (the highest category of importance, indicating flares covering more than 1200 millionths of the sun's visible hemisphere); this flare began at 0950 UT, March 23, and ended about four hours later.

The flare was followed immediately by an extremely severe radio-noise storm on the sun. This storm produced radio emissions at all observed frequencies, from about 170 to 9400 megacycles, and a short-wave radio fadeout, which occurred between 0953 and 1309 UT, March 23. (J. F. Denisse, of Meudon Observatory, Paris, reported that at the lower frequencies the storm was one of the largest and longest ever recorded.)

The sudden commencement of a geomagnetic storm at 1540 UT, March 25, signaled the arrival at the earth of the cloud of solar gas presumably ejected by the flare. This was followed shortly by a pronounced decrease in cosmic-ray intensity at sea level.

Balloon Observations

High-altitude balloon data were obtained on the energy and composition of cosmic rays during the period of disturbance near Minneapolis (geomagnetic latitude 55°N). Balloon flights designated IGY 27, 28, and 29 were made on March 21 and 26 and on April 8, respectively. The balloons carried single counters and ion chambers, which record continuously the particle flux and the atmospheric ionization, and photographic emulsions for determining the precise nature of the particles involved.

Counting Rate and Ionization Intensity: Figure 1 presents the results of these measurements at an atmospheric pressure level of 10 millibars (about 102,000 ft). The ion-chamber curve shows constant and steady ionization on March 21 and a return to this condition by April 8. On March 26, however, the intensities measured by the single counter and ion chamber as the balloon reached peak altitude, at 1300 UT, were about 23% less than the March 21 values. This is consistent with the "Forbush decrease" in cosmic-ray intensity following a solar flare. (These decreases are now thought to indicate the modulating effect of the beam of solar particles on pre-exist-

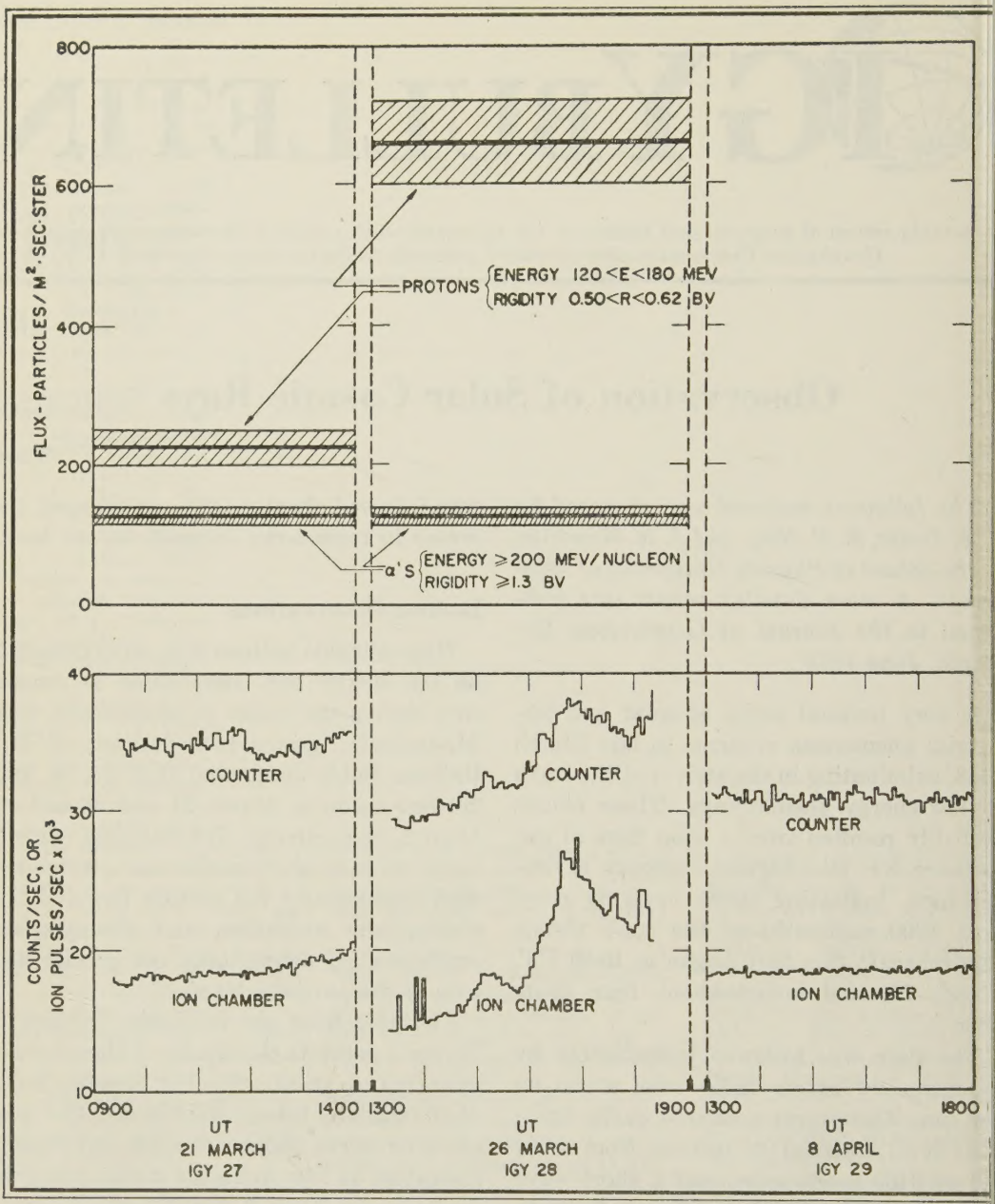

Fig. 1. *Counting Rates, Ionization, and Particle Composition as Measured on IGY Balloon Flights 27, 28, and 29. Upper part shows alpha-particle and proton flux measured by nuclear emulsions; lower part shows counting rates and ionization. The increase in ionization rate on March 26 agrees satisfactorily with the proton-flux increase shown by emulsions carried on the same flight.*

ing cosmic rays, causing a drop in intensity both at sea level and at high altitudes.)

On this occasion, the Forbush decrease was followed, about an hour after the balloon had reached ceiling altitude, by a sl*increase* in counting rate and in ionizatic This continued throughout the remainc of the flight, a period of six hours. Fr

analysis of the ratio of ion-chamber to single-counter readings it was determined that if the ionizing particles were protons their range was 33 gms/cm^2 (i.e., they would penetrate any material to a thickness at which a cm^2 column would weigh 33 gms) and their energy was about 200 million electron volts (mev).

(It is possible that the increase with time of counting rate and ionization during the IGY-28 flight may actually represent a latitude effect, since the balloon drifted from Minneapolis to Sault Ste. Marie, Michigan. No increase was observed in a simultaneous flight in Texas, at geomagnetic latitude 41°N.)

Nature of Particles: Detailed studies were made to determine the nature of the particles associated with this increase in cosmic-ray intensity. The upper part of Figure 1 shows the results of observations of alpha particles (He^{++}) with energies greater than 200 mev/nucleon (equivalent to a total energy of 800 mev/alpha particle) and of protons (H^+) with energies of 120-180 mev. (Protons are believed to make up about 90% of primary cosmic rays, with heavier particles, including alpha particles, comprising the remainder.) The equipment used measured almost all alpha particles but only protons of rigidities between 0.50 and 0.62 BV. (Magnetic rigidity = momentum/charge, and is a measure of the resistance of the particle to deflection by a magnetic field; here, expressed in billions of volts, or BV.)

It was found that the flux of alpha particles of rigidity greater than 1.3 BV did not change measurably, but the flux of protons within the narrow rigidity range measured increased by the large amount of 0.04 particles/cm^2·sec·ster. At solar maximum, the total particle flux is about 0.1 particles/cm^2·sec·ster, i.e., 0.1 particles pass through a cm^2 area each second from directions lying within a three-dimensional angle of unit area, or steradian. The average increase in flux for the IGY-28 flight was, therefore, nearly half the total primary proton flux. This increase is consistent with the flux of protons of energies below 200 mev estimated from the ion-chamber to single-counter ratio, which was .06 particles/cm^2·sec·ster. During the event, protons arrived with rigidities as low as 0.5 BV, far below the rigidity cut-off of 1.0 BV for this geomagnetic latitude, inferred by P. Fowler, P. S. Freier, and E. P. Ney from previous direct-energy measurements. (Normally, only the higher-energy particles can penetrate the earth's magnetic field at the equator; lower-energy particles can penetrate only to certain geomagnetic latitudes, depending on their energies; very low-energy particles can penetrate only in polar regions.)

Sea-Level Intensity

A plot of sea-level neutron intensity at Deep River, Canada, March 20–April 10, is shown in Figure 2. In the period March 25–26 a drop in intensity of nearly 10% was measured, but it can be seen that the counting rate recovered from the decrease by early April. (These data were obtained by H. Carmichael.)

Cosmic-Noise Absorption

Data on the cosmic-noise absorption at Fort Yukon, Alaska, associated with the cosmic-ray phenomena described was supplied by H. Leinbach and G. C. Reid (Fig. 2, bottom). They report a very large absorption, amounting to 10 decibels, beginning abruptly on March 26 at the time of the sudden commencement of the magnetic storm. Even at night, on the nights preceding and following March 26, the absorption of cosmic noise was 3 db.

It is thought that this type of polar-cap cosmic-noise absorption may be caused by the arrival at the earth of charged particles, increasing ionization in the D-region of the earth's ionosphere. The particles appear to have been confined to the solar beam, since they were observed only when the earth entered the beam, at 1540 UT, March 25. The

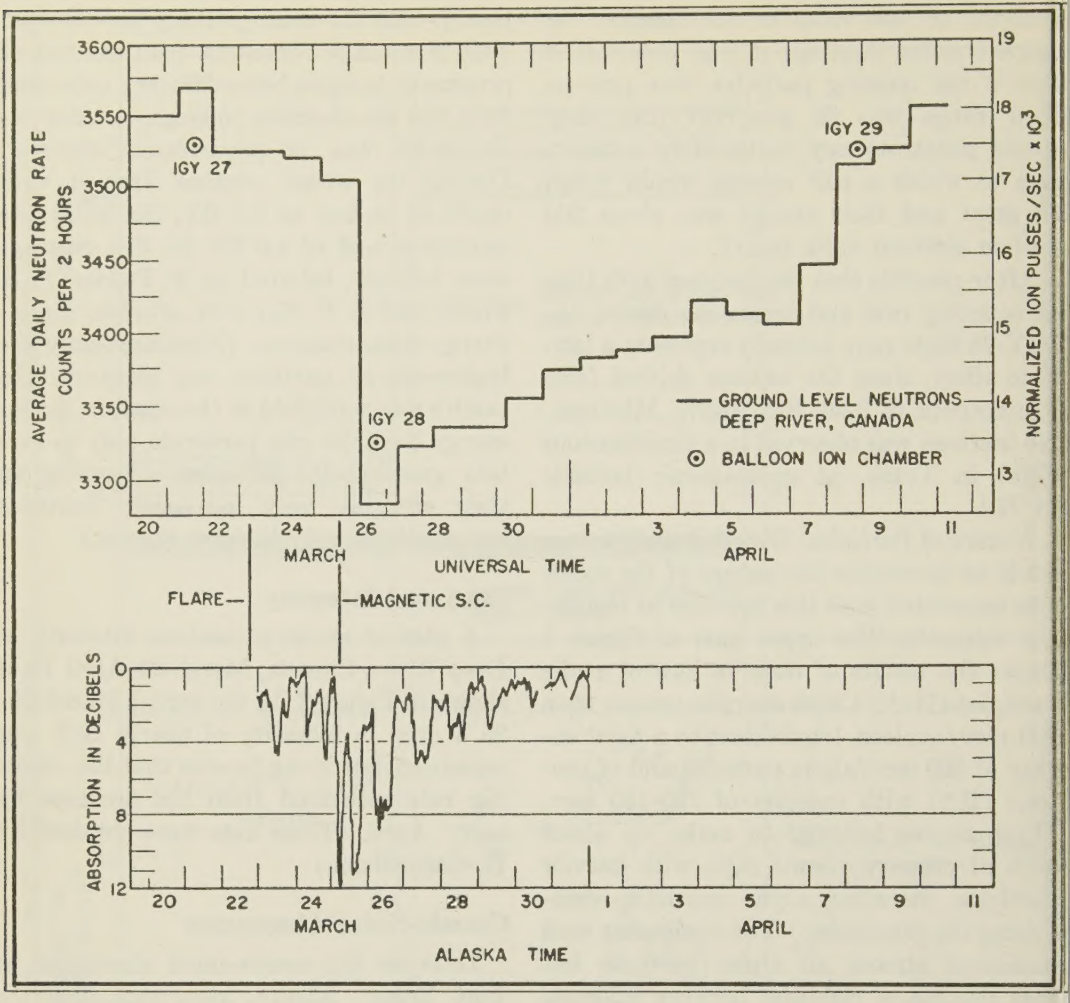

Fig. 2. *Sea-Level Neutron Intensity at Deep River, Canada, and Cosmic-Noise Absorption at Fort Yukon, Alaska. The neutron-intensity record also shows the total ionization rate at balloon ceiling altitude for IGY 27, 28, and 29.*

March 1958 disturbance may be the most intense event of this type observed up to that time.

(A second and even more intense event of this type was observed on May 11–12, 1959. The Minnesota investigators were informed by H. Leinbach that cosmic-noise absorption had reached 17 db on May 11. Accordingly, on May 11 and 12, five balloon flights were made. The observations showed that the May 11 event produced at least 50 times as many particles at balloon altitudes as were observed in the March event. In the more recent event, the solar beam apparently consisted almost entirely of protons.)

Conclusions

The significant features of this event are (1) the presence of particles with rigidities lower than the normal cut-off rigidity for the geomagnetic latitude of Minneapolis and (2) the delayed arrival of cosmic rays following the solar flare of March 23.

The University of Minnesota investigators believe that the presence of low-rigidity

particles indicates distortion of the Stoermer cut-offs (the minimum particle energies needed to penetrate the geomagnetic field) by the solar beam ejected by the flare. They believe also that the late arrival of cosmic rays indicates storage in the solar corona of particles accelerated during the solar flare of March 23. The storage may have taken place between March 23 and March 30 and the particles may have arrived at the earth after being diffused into the magnetic channel associated with the solar beam.

Two other possible causes for the late arrival of the cosmic rays were considered: (a) The flare of March 23 produced a magnetic channel; subsequent solar activity accelerated the cosmic rays and injected them into the channel. This was ruled out because no major flares occurred in the period following March 23 to effect the acceleration and injection. (b) Particles trapped in the Van Allen radiation region (see *Bulletin No. 21*) were released by magnetic perturbation caused by the solar cloud. This was deemed improbable because of the polar-cap cosmic-noise absorption effects reported by Leinbach.

Rocket Studies of the Equatorial Electrojet

The following report is based on material supplied by Laurence J. Cahill, Jr., of the State University of Iowa. A more detailed account has been published in the Journal of Geophysical Research, *May 1959.*

Variations of the earth's magnetic field, long observed at the surface, are believed caused by electrical currents flowing in the ionosphere. However, the height, thickness, and current-density structure of these currents cannot be determined solely by ground-level measurements. Hence, the State University of Iowa included in its program of upper-atmosphere research the development of a small, light-weight magnetometer for use in rockoons. (*Bulletin No. 11* contains a brief description of the instrumentation and of the rockoon technique—which employs a balloon to lift a rocket to firing height.)

Successful flights were made during the IGY in both polar regions and in the mid-Pacific (Line Islands region), where the existence of the equatorial electrojet (see *Bulletin No. 17*) was further confirmed by direct measurements. This report is concerned with the equatorial electrojet studies.

The height and current density of the electrojet were measured at several latitudes during periods of magnetic calm and of moderate disturbance. In addition to the current layer previously predicted on the basis of ground-level measurements, another current layer was discovered slightly above the main electrojet current, and still another, flowing in the opposite direction, was found to the north.

The equatorial rockoon-magnetometer flights were made possible through the cooperation of Navy Task Force 43. SUI workers accompanied the USS *Glacier* on its cruise from Boston to the Antarctic during the Deep Freeze III expedition; in addition, the *Glacier* was allowed to deviate from its normal course for the Line Islands launchings and Navy personnel assisted with the launchings. Various SUI scientists, J. A. Van Allen in particular, supplied guidance and assistance in formulating the experiment, preparing the instrumentation, launching the rockoons, and reducing data.

Theory

The idea that variations in the earth's magnetic field observed at the surface are related to horizontal electric currents in the upper atmosphere is part of the "dynamo theory" of magnetic-field variations. In this theory, charged atmospheric particles are moved in tidal winds across the lines of force of the magnetic field, thus inducing electromotive forces in a direction perpendicular to the magnetic field. These electromotive forces cause positive and negative particles to move in opposite directions, setting up a system of electric currents in the atmosphere. Since the charged particles are provided by the horizontal ionospheric layers, the currents must likewise be principally horizontal. The tidal winds are related to the sun's movement across the sky; hence, the electrojet is primarily a day-time phenomenon.

The density of the electric current at any altitude above the surface depends on the velocity of the tidal winds producing the electromotive forces, the ionospheric conductivity at that altitude, and the strength of the magnetic field. Detailed information has in the past been lacking about the first two of these factors. Moreover, it seems likely that such information will for some time remain insufficient for detailed computation of the electric currents on the basis of the dynamo theory. However, the rocket magnetometer makes it possible to measure current densities directly and, along with electron-density measurements made by other rocket techniques, is supplying data which will help in computing conductivity more accurately.

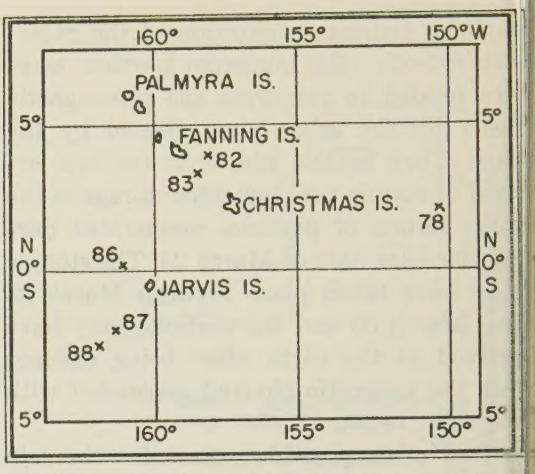

Fig. 3. *Location of Equatorial Electrojet Rockoon Flights, in the vicinity of the Line Islands.*

Flight Results

Six successful flights of the rocket magnetometer were made in the vicinity of the Line Islands (see Fig. 3 and Table 1). The records of three of these flights showed a normal approximate inverse-cube decrease with altitude in the intensity of the earth's magnetic field. The other three, flights 83, 86, and 87, apparently penetrated current layers in addition to recording the inverse-cube decrease.

The Scripps Institution of Oceanography established three ground-level magnetic ob-

Table 1. Flight Summary

Flight No.	(Oct. 1957) Date	Launching Time (at 165°W)		Location	Peak Alt. (km)
		Balloon	Rocket		
78	14	1216	1331	2°16′N, 150°23′W	113
82	17	1101	1216	3°56′N, 158°07′W	51
83	17	1244	1359	3°23′N, 158°41′W	127
86	18	1243	1356	0°02′N, 160°52′W	122
87	19	0750	0907	2°05′S, 161°05′W	129
88	19	1406	1519	2°31′S, 161°26′W	104

servatories in the Line Islands during the IGY to obtain new information about the equatorial electrojet through simultaneous observations at separate locations. These observatories supplied necessary information about the degree of magnetic disturbance during flights near them. Moreover, the rocket and ground-level measurements complemented each other: ground measurements supplied information on short and long-range changes in current intensity and on the location and periodic movements of the center of the current; rocket measurements provided a comparatively detailed picture of the extent in latitude and altitude of the electrojet and of its structure—the profile of current density with altitude.

East-West Current: Flight 83, in the electrojet region but somewhat to the north of the electrojet itself (Fig. 3), provided accurate and fairly complete data to a height of 125 kilometers, well into the ionosphere. The flight record shows an abrupt change of slope at 104 kilometers, indicating penetration of a current sheet. This slope change is a decrease, however; hence, the current must flow east-west in this region, directly opposite to the predicted direction of the equatorial electrojet. Since the flight curve resumes its original slope at 108 kilometers, the current sheet is rather thin. The record for the downward leg also shows the slope decrease at the same place that it appears on the upward-leg record, supporting the existence of this east-west current.

There is some evidence that this current is quite limited in lateral extent and would produce only very small ground-level effects, even in the absence of the masking effect of the more powerful electrojet.

Figure 4 is a plot of current density against altitude computed for part of flight 83, showing the east-west current layer detected during the flight.

Electrojet Flights: Flight 86 was launched 30 miles northwest of the Jarvis Island magnetic observatory at 1356 local time.

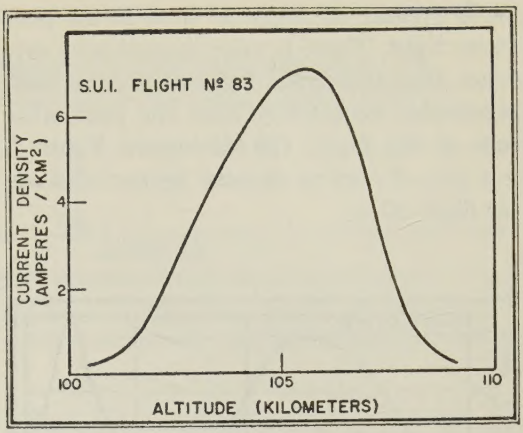

Fig. 4. *Current-Density Plot for Flight 83.*

Since ground-level measurements indicate that the electrojet appears to be closer to this observatory than to the others, it was expected that a launching at this location and time would result in penetration of the electrojet current.

The flight record shows an increase in slope at a height of 97 kilometers and a return approximately to the original slope at 110 kilometers, indicating that the rocket had passed through the electrojet in this region. (A rocket flight made during studies conducted by S. F. Singer and others in 1949 also entered the electrojet at approximately the same height.) Detailed plots of the flight record, however, reveal that above 110 kilometers the slope does not return entirely to its value at lower levels and that it again increases near 117 kilometers. Thus, two distinct current layers are indicated, with a layer of lower current density between them. Since the slope does not return completely to the lower-level value at the peak altitude reached by the rocket, 122 kilometers, the upper layer evidently was not completely penetrated.

The records for flight 87, southwest of Jarvis Island, also indicate penetration of the two current layers. The lower layer was found to be at the same altitude as in flight 86, but the upper layer was slightly higher. The current intensities were found to be

much greater on flight 87 than in the previous flight. There is some inconclusive evidence that the upper layer may have been penetrated completely near the peak altitude of this flight, 129 kilometers. Figure 5 is a plot of current density against altitude for flight 87.

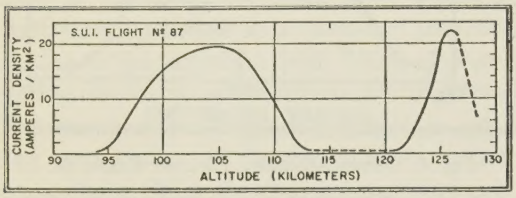

Fig. 5. *Current-Density Plot for Flight 87. Note two peaks, representing upper and lower current layers of electrojet.*

Intensity and Structure of Electrojet

Records from flights 83, 86, and 87, taken together with corresponding records from the Line Islands observatories, were used to sketch the intensity and structure of the equatorial electrojet.

Intensity: The departure from the normal inverse-cube decrease at the peak altitude of flight 86 was 138 ± 10 gamma (γ). (The sea-level magnitude of the earth's magnetic field at the equator is 34,000γ.) The contribution of the current sheet to the daily magnetic variation at sea level, as estimated from the rocket measurements, is 59 ± 4γ. This value, although in excellent agreement with the ground-level measurements, is surprising since the upper current layer was not completely penetrated. It is thought that only ⅔ of the value of the daily variation at sea level is attributable to the overhead current sheet (the Jarvis value was 90 ± 6γ at the time of the flight).

On flight 87, the total departure from the normal inverse-cube decrease at peak altitude was 300 ± 20γ, slightly more than twice that measured on flight 86. The expected contribution to the daily surface variation in this region is 127 ± 9γ, whic does not agree with the value based o surface measurements (137 ± 4γ, or ⅔ th total measured value of 206 ± 6γ) quite a well as in the previous flight. This may b because ground measurements of overhea currents in the Jarvis region at the time c flight 87 indicated they were more intens than those found by rockets in the vicinit of flight 87, about 120 miles farther soutl

Variograph records of the vertical com ponent of the magnetic field (F) from Pa myra and Jarvis indicate local regions c more intense current imbedded in the elec trojet. Although the main daily variation i F at these stations is similar, small, tem porary fluctuations are opposite in phas This indicates that the source of these sma fluctuations lies between Jarvis and Pal myra. The center of the electrojet, howeve appears to be south of Jarvis.

The currents measured up to heights c 129 kilometers appear to be of sufficien magnitude to account for all of the ground level daily variations. However, it is be lieved there may be additional current lay ers above the peak rocket altitudes reache Such currents might be too weak to produc observable variations at the ground, or the could be in pairs flowing in opposite direc tions, cancelling out each other's effects.

Structure: Figure 6 is a vertical cross section of the equatorial electrojet based o extrapolations from the available experi mental data. It is intended only as a graphi portrayal of the data and not as a precis or reliable picture of the actual electroje

The total width of the electrojet is esti mated at about 300 kilometers, with th northern boundary lying between the site of flights 83 and 86. (The width estimat agrees with a ground-level latitude surve by C. A. Onwumechilli, of the Universit of Nigeria, and with electrojet conductivit calculations by D. F. Martyn.) Flights 8 and 87, as well as earlier measurements b Singer and others, fix the bottom of th lower electrojet layer at a height of 97 kilo

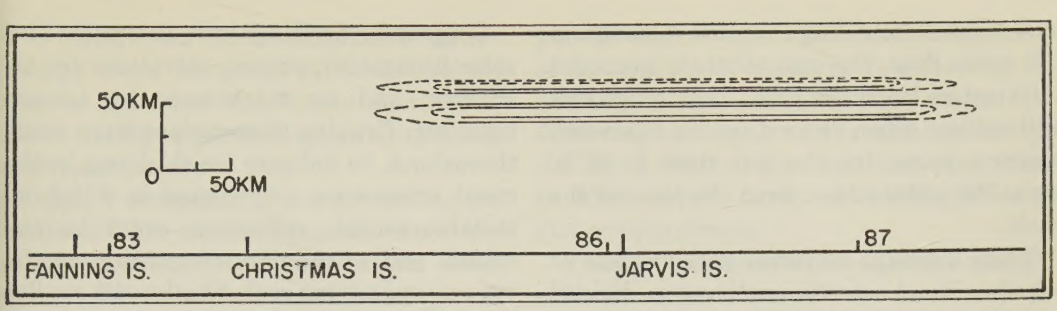

Fig. 6. *Cross-Section Showing Approximate Structure of Equatorial Electrojet. Inner lines represent regions of higher current density; numbers at bottom are flight numbers at their positions relative to the electrojet.*

meters. The top of the lower layer is at about 110 kilometers.

The lines within the layers in Figure 6 represent current-density regions, with density increasing toward the center of the layer. (Actual current densities vary daily and from day to day, and, as already mentioned, local regions of higher density may be present.) The altitude and thickness of the upper layer, as well as the interval between the two layers, appears to be variable.

Variations in the intensity and height of the upper layer may be related to the degree of magnetic disturbance or to several other factors, such as season, time of day, or phase of the moon. The flights described were made on both magnetically disturbed and on magnetically quiet days, shortly before the autumnal equinox, and when the moon was in the last quarter.

The presence of two current layers at the equator, rather than the single layer predicted from ground studies, must still be explained. A possible explanation is the presence of a high-electron-density layer above the altitude of peak ionospheric conductivity (near 100 kilometers). An intense sporadic-E reflection has been observed near the magnetic equator in the same region as the electrojet. (Sporadic-E refers to clouds, or patches, of ionization in the E-region of the ionosphere which reflect radio waves.) This sporadic-E layer could be responsible for one of the current layers, but which current layer might be due to the sporadic-E and which might be due to the peak in conductivity is not yet clear.

Antarctic Traverse Reports

Related materials from two sources bearing on the possible existence of a trans-Antarctic trough, along with other traverse findings, are presented in the following report. The first part of the report is based on a paper given at the May 1959 meeting of the American Geophysical Union (AGU) by Edward Thiel and Ned A. Ostenso. The second part is based on a paper presented by Charles R. Bentley and Ostenso at the same meeting. In both cases, the material was prepared at the University of Wisconsin.

I. AIRBORNE TRAVERSE, 1958–59

A principal result of the first season of IGY Antarctic oversnow traverse activity was the discovery that the Filchner Ice Shelf, which borders the Weddell Sea, extends much farther inland than had previously been supposed. Beneath its eastern

part, seismic sounding revealed a trough in the ocean floor, the axis of which averaged 1100 meters below sea level. This trough was still evident when crossed by the Ellsworth traverse party for the last time at 82°S, some 300 miles inland from the front of the shelf.

These findings reopened the question of whether the Antarctic continent is divided by a down-warped, ice-filled depression connecting the Ross and Weddell Seas.

The airborne traverse followed a path at right angles to the hypothetical trough. Traveling in a Navy aircraft, the three-man scientific team made seven landings along meridian 130°W. They covered some 400 miles between the Harold Byrd Mountains and the Executive Committee Range. (See Fig. 7.)

Geographic positions were determined by solar navigation, surface elevations by altimetry, and ice thicknesses by seismic sounding. Gravity observations were made throughout, to indicate ice thickness in the event areas were encountered in which no suitable seismic reflections could be obtained, and to provide information on the type of underlying rock. Shallow pit studies and coring determined the mean annual temperature and snow accumulation, and magnetic declinations were measured. Three hours' work was required at each station.

The seismic program at each station consisted of a vertical sounding for ice thickness, and of small explosions at each end of a 330-meter cable on the ice surface; the cable contained 12 geophones, equally spaced, to determine the average seismic-

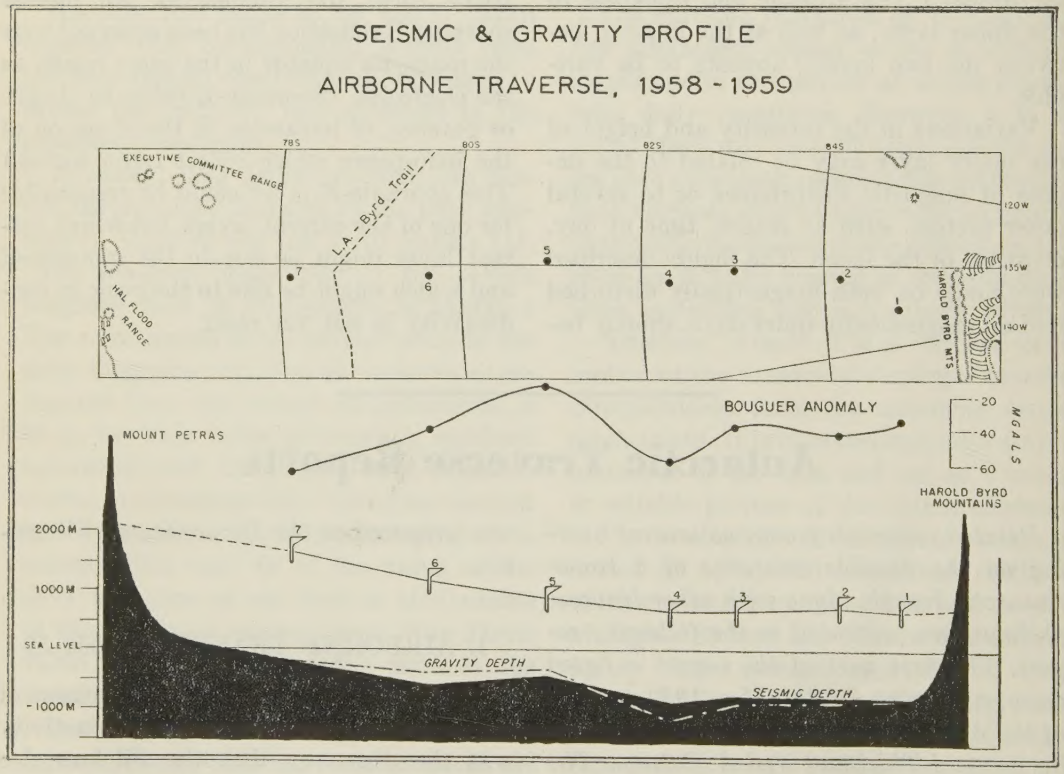

Fig. 7. *Seismic and Gravity Profile Obtained on Airborne Traverse. Ice is shown to be grounded at all seven stations between the mountain ranges, lending support, in this region, to the thesis of a connection between the Ross and Weddell Seas in the form of a down-warped, ice-filled trough.*

wave velocity for the ice column. Good reflections were obtained at five stations; those at the other two were usable but of poorer quality, perhaps because of nearness to crevassed areas.

Figure 7 contains a profile presenting the results of this seismic program. Since the ice is shown to be grounded at all seven stations between the mountain ranges at either end of the line, there appears to be virtually no possibility of water interchange between the Ross and Weddell Seas. However, the profile does appear to support the thesis of a down-warped, ice-filled trough connecting the two seas. Nevertheless, additional data, especially on the area to the east, are needed.

Related Results

Some further light is thrown on the trough problem by data so far available from the Marie Byrd Land oversnow traverse of 1958–59, which was in the field at the same time as the airlifted group. (This traverse is discussed in more detail in Part II, where it is referred to as the Horlick Traverse.) It traveled a triangular path: leg A, from Byrd Station across the hypothetical trough region to the foot of the Harold Byrd Mountains; leg B, eastward roughly paralleling the great trans-Antarctic range; and leg C, back to Byrd Station, once again crossing the trough region.

Leg A produced results similar to those found by the airborne party along 130°W —grounded ice resting on a rock surface below sea level. Over much of leg B the buried rock surface was found to be above sea level; this is not surprising since it paralleled the mountains to the south of the axis of the hypothetical downwarp. On the southern half of leg C the buried rock surface was found to be above sea level, with the important exception of a 40-mile gap where the rock descended to 1000 meters below sea level. Since the rock surface below Byrd Station is known to lie 1000 meters below sea level, any trough must pass through or near the Byrd Station area, or through the 40-mile gap found on leg C. (An earlier figure of about 1500 meters, or 5000 feet, for depth of the rock surface in the Byrd Station area has been corrected to 1000 meters, based on additional data and computations.)

To help determine whether such a trough actually extends across the continent or whether it is broken by a land bridge under the ice between the South Pole region and the Palmer Peninsula Mountains bordering the Weddell Sea, an airborne traverse along the 88°W meridian between the Horlick and Sentinel Mountains has been proposed for the coming Antarctic field season. This area is considered the most likely for such a connection because of its isolated nunataks and high snow surface.

II. MARIE BYRD LAND TRAVERSES

Study has been carried out to date on the results of three oversnow traverses in Marie Byrd Land. The first (Fig. 8) followed the pre-established trail from Little America Station to Byrd Station during the month of February, 1957. The second, or Sentinel, traverse proceeded clockwise around a loop to the northeast of Byrd Station between November 19, 1957, and February 19, 1958. The third (Horlick) traverse lasted from November 1, 1958, to January 20, 1959, and covered, in a counter-clockwise direction, a loop south of Byrd Station.

On all traverses, seismic reflection shooting was carried out at intervals of about 30 nautical miles, with gravimetric, magnetic, and altimetric measurements every three miles. Reflection shooting was supplemented by a large number of short refraction measurements in which the variations of seismic-wave velocities in the upper 50 meters of firn were studied, and by eight long refraction profiles which produced information concerning velocities throughout the icecap and in the rock beneath.

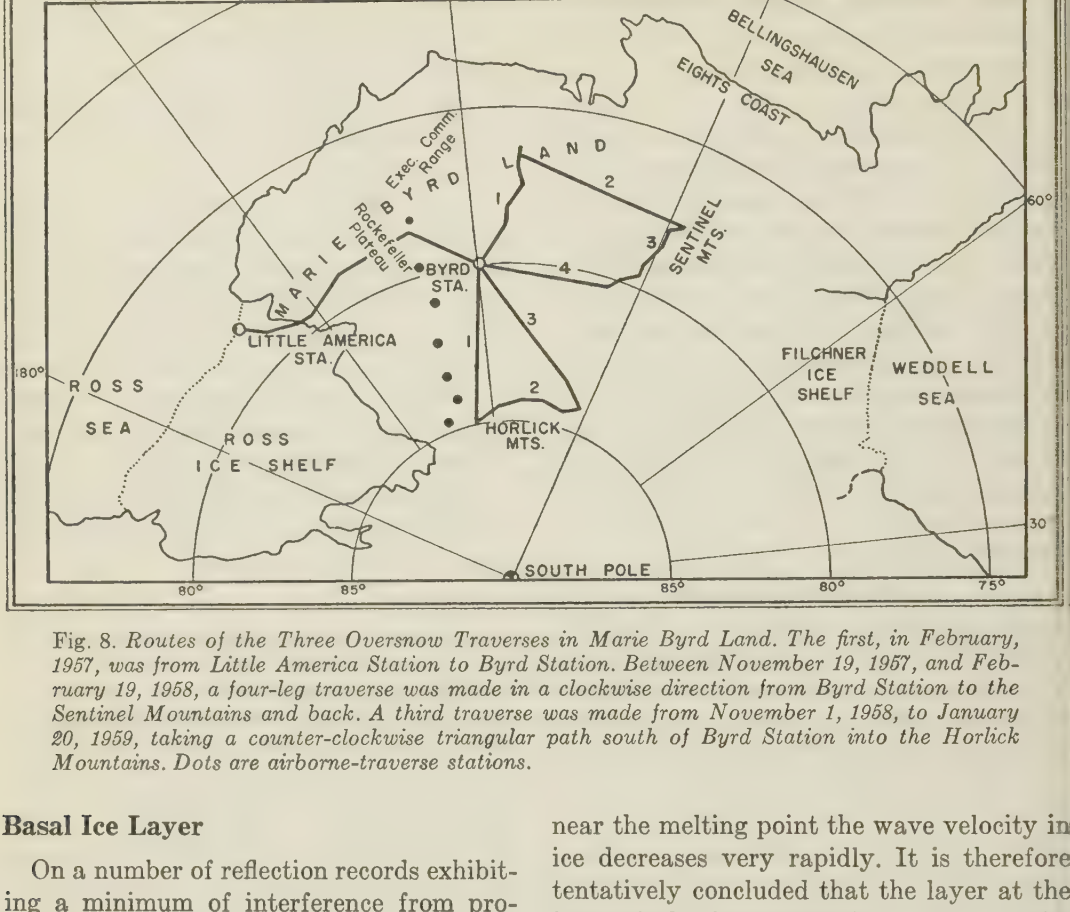

Fig. 8. *Routes of the Three Oversnow Traverses in Marie Byrd Land. The first, in February, 1957, was from Little America Station to Byrd Station. Between November 19, 1957, and February 19, 1958, a four-leg traverse was made in a clockwise direction from Byrd Station to the Sentinel Mountains and back. A third traverse was made from November 1, 1958, to January 20, 1959, taking a counter-clockwise triangular path south of Byrd Station into the Horlick Mountains. Dots are airborne-traverse stations.*

Basal Ice Layer

On a number of reflection records exhibiting a minimum of interference from prolonged surface noise, reflected energy was received several tenths of a second before the main echo from the ice-rock interface. This early reflection was particularly noticeable on records obtained throughout the second leg of the Sentinel Traverse. By combining results of vertical and wide-angle reflections it was possible to determine the existence of a layer at the base of the ice, having a thickness of about 300 meters, in which the primary wave velocity is approximately 3600 m/sec, as compared with 3850 m/sec in the icecap proper.

A comparison of the amplitudes of the early and main reflections shows that the density of the layer must be very close, if not equal, to that of ice. G. de Q. Robin has shown in laboratory experiments that near the melting point the wave velocity in ice decreases very rapidly. It is therefore tentatively concluded that the layer at the base of the icecap consists of ice at the pressure melting point, perhaps either a zone of stagnant ice or a zone of flow. Further study of this layer during future traverses is planned.

Cross-Sections to Bottom

Seismic reflection and gravity results have been combined to draw cross sections of the icecap along the paths shown in Figure 9 for the Little America—Byrd Station Traverse and for the Sentinel Traverse, and, in Figure 10, for the Horlick Traverse. The dashed line in Figure 10 shows an approximate position of sea level relative to the rock surface if the ice were removed and allowance made for "isostatic rebound." (This adjusted position of sea level is here referred to as reduced sea level.)

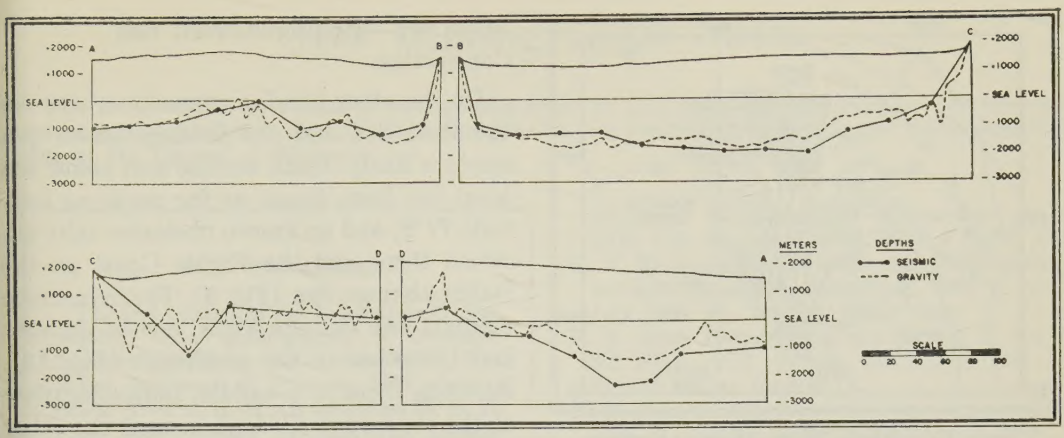

Fig. 9. *Seismic and Gravity Depth Sections Obtained on Byrd-Sentinel Traverses. (Scale in nautical miles.) From the Ross Ice Shelf to the end of the first leg of the Sentinel Traverse, the rock surface is as shown in Section A-B, moderately rough with all but a few peaks well below sea level. The third leg of the Sentinel Traverse, Section C-D, reveals a very rough, mountainous rock surface largely above sea level. The second and fourth legs of this traverse, Sections B-C and D-A, show a deep, smooth, basin-like surface.*

From the Ross Ice Shelf—Rockefeller Plateau boundary to the ends of the first legs of the Sentinel and Horlick Traverses, the picture is generally the same. The rock surface is moderately rough with all but a few peaks well below sea level. The eastern parts of both the Sentinel and Horlick Traverses (leg 3 of the former, leg 2 and the first half of leg 3 of the latter) exhibit a very rough, mountainous rock surface largely above sea level. In intervening areas on the Sentinel Traverse (legs 2 and 4) a deep, smooth, basin-like surface is seen, separated from the mountainous area by a transition zone more or less at reduced sea level.

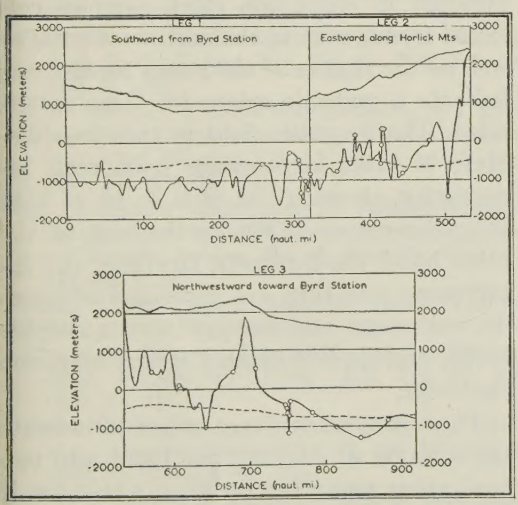

Fig. 10. *Cross Sections of the Icecap and its Underlying Rock Based on Seismic and Gravity Readings Taken on the Horlick Traverse. The dashed line shows sea level as it would be if the ice were removed and allowance made for isostatic rebound.*

Figure 11 is a map of Marie Byrd Land on which are shown contours of the ice surface and a general division into zones depending upon the nature of the rock floor. To the west is an island zone in which the rock level is generally below reduced sea level but with scattered points protruding above. East of this in the northern part of the area is the basin zone, typified by a smooth rock surface beneath the ice. To the west is the high, rugged mountain zone—from the Ross Ice Shelf to the Sentinel Mountains. Between the basin and mountain zones is a transition zone in which the rock surface is more or less flat and at a reduced sea level. The distinction between the island, basin, and transition zones is lost farther south.

The continuity of the mountain zone deserves examination if a decision is to be made on the existence or absence of a trough

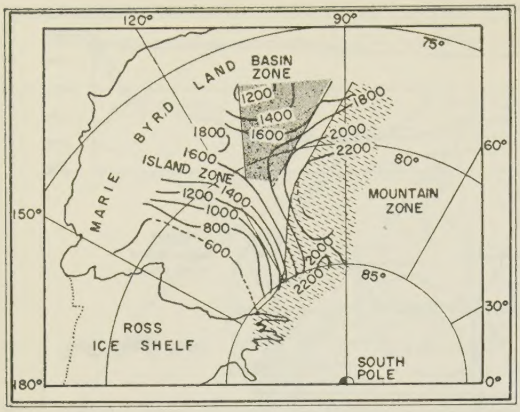

Fig. 11. *Marie Byrd Land Divided into Three Zones According to the Nature of the Rock Floor. In the island zone to the west, rock level is generally below "reduced" sea level, i.e., the adjusted sea level if ice were removed and allowance made for isostatic rebound. To the north is a basin zone, with a smooth rock surface well below reduced sea level. The mountain zone to the east has a high and rugged rock surface beneath the ice. The contours (in meters) show the topography of the ice surface.*

connecting the Ross and Weddell Seas. North of 81°S the Sentinel Mountains and their extension above and below the ice surface form a continuous barrier. In the south, the Horlick Mountains and the subice topography protrude above reduced sea level as far north as 82½°S, with the exception of the narrow deep spot shown on the third leg of the Horlick Traverse at 83½°S.

Thus, it appears that there is no *broad* trough south of 82½°S connecting the Ross and Weddell Seas. Between 81°S and 82½°S there is no north-south coverage far enough east to bear on the problem. More information must therefore be obtained in the vicinity of 90°W before the possibility of a below-sea-level connection can be eliminated.

Ross Sea—Bellingshausen Sea Connection

On the other hand, a connection between the Ross Sea and the Bellingshausen Sea appears likely. Rock surface well below sea level has been found as far north as latitude 77°S, and no known obstacles exist between there and the Eights Coast on the Bellingshausen Sea (Fig. 8). The ice surface exhibits two definite highs, one in the east and the other in the northwest (Fig. 11). Between them is a saddle, indicating flow of the ice from each high toward the other and off to the southwest and north. The profile of leg 1 in Figure 10 shows that the low ice-surface elevations south of Byrd Station are not a reflection of sub-ice topography, and must therefore be attributed to the pattern of ice flow. Thus, the surface contours suggest that there were once two separarate ice caps, one centered on the area of the Executive Committee Range and the other along the Sentinel—Horlick axis, and that these two caps converged on the water-covered zone between them.

Geological and magnetic data show the mountains in the two areas to be entirely different in character. Rock samples collected from peaks in the northwest area, as well as the shapes of the peaks themselves, indicate a volcanic origin for these mountains. The magnetic field in this area displays a strong dependence upon rock topography, showing the rock to be of high magnetic susceptibility. In the east, on the other hand, the Sentinels, Horlicks, and intervening nunataks are composed of granite, sediments, and low-grade metamorphic rocks, and do not exhibit strong magnetic character.

Thus, present evidence seems to indicate the division of Marie Byrd Land into two land areas separated by what would be, if the ice were removed, an area of open water running from the Ross to the Bellingshausen Sea.

IGY Bibliographic Notes

This is the twelfth of a series of bibliographic notes on IGY programs and findings. The references are selected largely from an IGY bibliography under preparation in the Science and Technology Division of the Library of Congress.

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